APPENDIX G

Pump Test and Modeling Technical Memorandum

ATTACHMENT 4

Aquifer Pumping Test and Development and Results of Groundwater Flow and Fate-and-Transport Model

URS

TECHNICAL MEMORANDUM

TO: Don Gruber, Project Manager, ITSI

FROM: Eddy Teasdale, PG

DATE: December 16, 2009

SUBECT: **Development and Results of Groundwater Flow and Fate-and-Transport Model for the Cooper Drum Superfund Site, South Gate, California**

I. INTRODUCTION

This technical memorandum describes the numerical groundwater model developed for the Cooper Drum Superfund Project (Site) in South Gate, California The model uses particle-tracking simulations to predict capture zones of the proposed extraction system. The model also includes a fate-and-transport component that can be used to predict migration of chemicals of concern (COCs) in groundwater at the Site.

II. HYDROGEOLOGIC CONCEPTUAL MODEL

The conceptual model serves as a basis for the numerical model. The conceptual model summarized here is based on information in existing Site documents and discussions with the long-time Project Manager. Input to the numerical model included hydraulic conductivity, groundwater recharge, and chemical properties of COCs. Groundwater model boundaries are based on real world conditions. Input parameters may have been modified during model calibration, but the modifications were restricted to reasonable real world ranges.

Site-Specific Geology

The local geology and hydrogeology is briefly described below. A more complete description of the regional and local geology and hydrogeology can be found in the *Remedial Design Technical Memorandum Field Sampling Results, and Monitoring Well Installation and Groundwater Sampling Results, Addendum Number 4* (Innovative Technical Solutions Inc. [ITSI], 2010), which is based in part on the *Geohydrology, Geochemistry, and Ground-Water Simulation-Optimization of the Central and West Coast Basin, Los Angeles, County California* (United States Geological Survey [USGS], 2003).

The Site is located in the West Coast Basin of the Los Angeles Coastal Plain and extends from Santa Monica Bay east to the Newport-Inglewood uplift, and from the Ballona Escarpment on the north to Palos Verdes and San Pedro Bay to the south. The Site is underlain by approximately 1,500 feet of fresh water-bearing strata consisting of (from youngest to oldest) the Older Dune Sands, the upper Lakewood Formation (including the semi-perched aquifer and the Bellflower aquitard), the lower Lakewood Formation (including the Gage aquifer), the San Pedro Formation (including the Silverado aquifer), and the Upper Pico Formation.

Stratigraphy is generally consistent across the Site. Interbedded silts, clays, and silty sands occur from the ground surface to approximately 60 feet below ground surface (bgs). These sediments are representative of the Bellflower aquiclude, which incorporates the perched aquifer system. The Bellflower aquiclude overlays the Gaspur aquifer, which extends to a depth of approximately 110 feet bgs. The Gaspur aquifer then overlays the Exposition aquifer. Municipal groundwater production occurs from the Exposition aquifer (part of the Lakewood Formation).

Site-Specific Hydrogeology

Groundwater elevations beneath the Site occur at elevations of approximately 51 to 52 feet about mean seal level (msl). The semi-perched Bellflower aquiclude is underlain by silty sands of the Gaspur aquifer. The Gaspur aquifer has been furthered divided into shallow, intermediate, and lower aquifer for better representation of the volatile organic compounds (VOC) concentration.

On this basis, the groundwater beneath the Site has been separated into five zones: shallow perched, the shallow Gaspur, intermediate Gaspur, lower Gaspur, and Exposition. Groundwater within the semi-perched and Gaspur aquifers primarily flows to the south; but it also has a southwesterly component in the lower Gaspur aquifer, especially near the southern portion of Southern Avenue. A north to south flow direction is generally consistent with historical water levels measured at the Site as referenced in groundwater monitoring reports. Flow variations in this area may be or may have been influenced by several factors that include but are not limited to the natural topography, which would suggest that groundwater flow would be predominantly to the southwest, toward the ocean.

In general, VOCs and 1,4-dioxane (1,4-D) are in the shallow, intermediate, and lower intervals of the Gaspur aquifer.

Aquifer Parameters

Aquifer parameters initially input in the model were based on results from historical pilot study injection tests and historical and 2009 aquifer tests performed at the Site. Table 1 summarizes the hydraulic conductivities calculated in these aquifer tests, and Appendix A provides details about the 2009 aquifer test. Effective porosity was estimated at 0.3 based on the lithology. Values for total organic carbon (TOC) and bulk density were derived from soil samples collected during the Cooper Drum remedial investigation feasibility study (RI/FS) (URS, 2002). Total organic carbon ranged from 0.2 to 0.03 percent, and bulk density ranged from 91.02 pounds per cubic foot (lbs/ft^3) to 101.92 lbs/ft^3 (URS, 2002).

Table 1. Summary of Hydraulic Conductivity, Cooper Drum Site

Test Area	Aquifer Test Date	Hydraulic Conductivity (feet/day)
EW-3 (McCallum Avenue)	May 2009	32 to 57
EW-1 (Source Area)	April 1999	33 to 54
EW-2 (Source Area)	March 2001	26 to 47

Groundwater Elevations, Flow Directions, and Gradients

Information on locations of wells used to collect data for interpretation of groundwater elevation, flow direction, and gradient at the Site and well specifications are included in the *Remedial Design Technical Memorandum for Field Sampling Results, and Monitoring Well Installation and Groundwater Sampling*

Results, Addendum Number 4 (ITSI, 2010). Hydrographs of shallow zone wells show minor seasonal groundwater level fluctuations and larger multi-year fluctuations that may be related to regional pumping and recharge. Historical shallow zone groundwater elevations (from 1990 to present) range from approximately 51 to 56 feet msl. A comparison of water levels in well pairs indicates vertical gradients are generally less than a few tenths of a foot and may be either upward or downward in a given well pair. This relatively flat gradient is expected in a system with no significant layering and high permeability.

Contoured potentiometric surface maps of historical groundwater levels indicate a generally southward flow direction. The hydraulic gradient across the model area is approximately 0.001 based on May 2009 water level data (URS, 2009).

Groundwater Recharge

Because the Site is almost entirely covered with asphalt and concrete, limited recharge was assigned to the model. Irrigation and precipitation in small areas of grass and vegetation and other areas not covered by impermeable surfaces within the model domain may provide some recharge to groundwater in this area. Recharge rates were assigned to the model based on precipitation data collected by the Los Angeles Civic Center (LLC) rain gauging station, located in the Los Angeles River Basin of the South Coast Hydrologic Area, near Los Angeles, California. (California Data Exchange Center [CDEC], 2009). Rates of 1 percent (%) of the average daily precipitation (professional judgment based on asphalt coverage) were input to the model as groundwater recharge. There are no unlined rivers or streams near the Site or model domain.

Groundwater Pumping

No active groundwater pumping occurs on the Site; however, there are municipal supply wells completed within the Exposition aquifer. Several of these municipal wells are close to the Site. Based on recent aquifer test data (Appendix A), there does not appear to be a hydraulic connection between the Gasper and Exposition aquifers in the vicinity of the Site.

Contaminant Distribution

Trichloroethene (TCE), cis-1,2-dichloroethane (cis-1,2-DCE) and 1,4-D are the primary COCs in groundwater at the Site. Contoured isoconcentrations for these three contaminants using May 2009 data are included in the *Remedial Design Technical Memorandum for Field Sampling Results, and Monitoring Well Installation and Groundwater Sampling Results, Addendum Number 4* (URS, 2009).

III. GROUNDWATER FLOW AND FATE-AND-TRANSPORT MODEL DEVELOPMENT

The Site numerical model consists of two models: a groundwater flow model and a fate-and-transport model. The two are linked by an interface in the model processor. Depending on the modeling objectives, the groundwater flow model can be operated independently of the transport model; however, when transport simulation is needed, both the flow and the transport models are required.

Model Software

The groundwater flow and fate-and-transport models were developed using the Brigham Young University Environmental Modeling Research Laboratory (EMRL) Groundwater Modeling System (GMS), Version 6.5 (EMRL, 2008). GMS is a comprehensive graphical user interface (GUI) for performing groundwater simulations. GMS provides a graphical preprocessor/postprocessor interface to several groundwater modeling codes: MODFLOW, MODPATH, MT3DMS, RT3D, FEMWATER, SEEP2D, NUFT, and UTCHEM. The EMRL of Brigham Young University, in partnership with the WES, developed the GMS interface. The GMS was used to develop the Cooper Drum Site conceptual hydrogeological model and to convert it into groundwater flow and transport models. All modeling codes and geological software tools used during this modeling effort are summarized below.

EarthVision 7 Geological Model. EarthVision 7 is a three-dimensional (3-D) modeling tool commonly used in oil exploration. It was used for this effort to update the 3-D geological model that has been used to support the groundwater monitoring program at the Site. Use of this sophisticated 3-D modeling tool was the most accurate, efficient, and convenient method for developing the structure of the groundwater model for this Site.

MODFLOW Groundwater Flow Model. The computer code selected to model groundwater flow beneath the Site was MODFLOW, a 3-D, cell-centered, finite difference, saturated flow model developed by the USGS (McDonald and Harbaugh, 1988). GMS provides an interface to the updated version, MODFLOW 2000 (Hill et al., 2000). Based on the information available, the uncertainties in site-specific information, the hydrogeologic complexity at the Site, and the modeling objectives, MODFLOW was considered an appropriate groundwater flow code.

MODPATH Particle-Tracking Model. Particle-tracking simulations provide a convenient means of visualizing groundwater flow paths. This is particularly useful in evaluating capture zones around a pumping well. MODPATH was selected as the particle-tracking program for this effort. MODPATH is a 3-D particle-tracking program that enables reverse and forward tracking from sinks (wells) and sources, respectively. MODPATH was developed by the USGS (Pollock, 1994). GMS has updated the interface for MODPATH to a seamless module that couples with MODFLOW 2000. MODFLOW flow modeling results (direction and rates of groundwater movement) are among the inputs for MODPATH runs.

MT3DMS Groundwater Transport Model. Contaminant transport simulations were conducted using the MT3DMS groundwater contaminant transport model code (Zheng and Wang, 1999). MT3DMS is an improved version of the MT3D model developed in 1990 (Zheng, 1990). It has improved numerical solvers that make the model more stable and help prevent model-induced numerical oscillations. GMS provides a module that links MODFLOW groundwater flow information to MT3DMS. MT3DMS uses this modeling output to simulate contaminant transport using the MODFLOW simulated groundwater flow field.

Parameter Estimation System (PEST). PEST is a model-independent parameter optimizer (Doherty, 2002). It was selected to shorten the time and improve the groundwater model calibration process. The typical calibration process for groundwater flow or transport models is iterative. The model with a specific set of parameter inputs is started; then the model results are compared to calibration targets (e.g., groundwater elevations at specific locations). After the comparison, the model is revised, and the process is repeated until the model output adequately simulates the calibration data set. GMS provides a module that links PEST with MODFLOW and MT3DMS to facilitate calibration.

Model Construction

The flow model simulates the perched sediments, the Bellflower aquitard, the shallow, intermediate, and lower Gaspur aquifer, and the regional Exposition aquifer. The model domain was defined to incorporate an area much larger than the Site to mitigate irregularities that occur along the model edges. The model grid consists of 196 rows and 122 columns, creating model cells ranging from 10 by 10 feet to 100 by 100 feet in area (Figure 1). The model was divided into six layers: two layers represent the shallow perched zone and the Bellflower aquiclude; three layers represent the shallow, intermediate, and lower Gaspur aquifer; and the bottom layer represents the Exposition aquifer. There is no lithologic basis for these divisions, but more layers allow greater discretization of well screen intervals, greater particle tracking resolution, and better representation of VOC concentration. The top of Layer 1 is ground surface. The tops of Layers 2, 3, 4, 5, and 6 were specified as 60, 40, 25, 0, and -20 feet msl, respectively. The bottom of Layer 5 is -20 feet msl, which corresponds to the top of the Exposition aquifer. The saturated aquifer thickness is approximately 150 feet for the entire model domain and approximately 60 feet for the Gaspur aquifer.

The spatial distributions of hydraulic conductivity values for the flow model were based on several factors, including Site geology, aquifer test results, literature review, and other groundwater models in the area. The hydraulic conductivity values were categorized into zones (polygons) in the conceptual model based on interpretation of the geologic data into a solid geology model. These hydraulic conductivity values were then mapped into the numerical groundwater model and adjusted later in the flow model calibration.

A 3-D geological model was produced to support visualization of the groundwater system at the Cooper Drum Site. This 3-D geological model was developed from lithologic data within the screen intervals of Site groundwater wells. Computer modeling of the geology was performed with a 3-D modeling software tool, EarthVision 7, following an interpretation of the lithologic information by a geologist. EarthVision 7 was used to develop 3-D correlations between the boreholes. The development was accomplished by interpolating numerically coded lithology onto a 3-D grid. The 3-D grid was then filled to produce a solid geologic model and fence diagrams. This method allows for rigorous analysis of the data and the geologic system through any location within the volume. In addition, EarthVision 7 contains a database of lithologic information, cone penetrometer testing data, and water levels with depth. This method saves time because fence diagrams and 3-D models can be viewed on a monitor from several oblique angles prior to printing.

The geologic model was directly imported into GMS. The geology was discretized into two separate, independent geological grids; a course grid with dimensions of 10 feet vertically by 500 feet laterally, and a refined grid with dimensions of 10 feet vertically by 50 feet laterally. The grids were interpolated to the MODFLOW 2000 grid. The refined grid was used to enhance the geology in the general area of the Site. The 10-foot-thick lithologic data were averaged over the total thickness for each MODFLOW 2000 layer. These layer-specific lithologic interpolations were verified by comparing boring logs and cross-sections of the area.

After the lithologic data were interpolated, individual hydraulic conductivity zones were digitized based on the interpolated lithology for each layer. The conductivity zones are refined within and around the Site because of the large amount of lithologic information available from the refined geologic grid. The hydraulic conductivity zones are larger and less variable farther from the Site, because the lithologic data density decreases.

Initial conductivity values were modified and refined during iterative PEST simulations to achieve a higher degree of calibration with measured water levels. Hydraulic conductivity values in PEST simulations were allowed to vary within a range of 10 to 200 feet per day. Hydraulic conductivity distributions estimated by PEST were then modified based on historical Site information, current contaminant plume distributions, and MODPATH particle-tracking simulations. Hydraulic conductivity values range from 0.1 to 200 feet per day; hydraulic conductivity distributions for the shallow, intermediate, and lower Gaspur aquifer (Layers 3, 4, and 5) are shown on Figure 2. Vertical anisotropy ratios (Kh/Kv) ranged from 0.1 to 10 in the Gaspur aquifer. Porosity in all layers was specified as 0.30.

Groundwater flow is essentially north to south; therefore, the boundaries were specified as general head boundaries (GHBs). GHBs were determined by extrapolating the contoured potentiometric surface across the model domain and incorporating these head values into the model boundaries. GHBs were assigned high conductance values (1,000 square feet per day [ft^2/day]) and essentially behave as specified heads. Assigned northern GHB heads range from approximately 48 to 56 feet msl; and assigned southern GHB heads range from approximately 46 to 50 feet msl. Initial flow model steady state simulations were based on May 2009 groundwater level data.

Flow Calibration

The flow model was calibrated to steady-state conditions and compared to the measured groundwater elevation data from May 2009. Once head errors at calibration target locations (existing monitoring wells) met predetermined criteria, the steady-state model was considered adequately calibrated.

An additional calibration technique using particle tracking was used. Simulated groundwater velocities were compared to measured velocities over time. Calibrated average model errors across the Site are listed in Table 2.

Table 2. Groundwater Flow Calibration Results, Cooper Drum Site

Error Type	Error	Calibration Criterion
Mean Error	0.26 feet	Not applicable
Mean Absolute Error	0.36 feet	Not applicable
Root Mean Squared Error	0.42 feet	± 1 foot
Model Error	6.5%	10%

This high degree of model calibration was probably due to the relative homogeneity and simplicity of the hydrogeologic system as well as the regularity of the potentiometric surface in this area. Simulated observed head data for the model is summarized on Figure 3.

Transport Model Setup

Based on the Site history and the historical analytical groundwater data, the contaminants modeled were TCE, cis-1,2-DCE, and 14D. These three contaminants were selected because of their relatively large plumes.

The simulated contaminant transport processes include advection, dispersion, and adsorption (retardation). Given the lack of geochemical data available during model construction, residual source mass, biodegradation, or other chemical transformations were not simulated. Future model updates could incorporate revised parameters as additional data are collected. The modeled processes are discussed hereafter.

Initial Transport Model Parameters

The transport model simulates the processes of advection, dispersion, and adsorption (retardation) based on the simulated groundwater flow conditions, the initial TCE, cis-1,2-DCE, and 14D concentration distributions, and the transport properties. The following subsections discuss specific parameters used in the transport model development.

Dispersion

Dispersion refers to the process whereby a dissolved contaminant will be spatially distributed longitudinally (along the direction of groundwater flow), transversely (perpendicular to groundwater flow), and vertically (downward or upward or both) because of mechanical mixing and chemical diffusion in the aquifer. These processes contribute to the development of the plume shapes and dimensions (the spatial concentration distributions of the dissolved contaminant mass in the aquifer). Selection of values for dispersivity (the parameter used here to represent dispersion) is a difficult process given the impracticability of measuring dispersion in the field; however, simple estimation techniques based on the length of the contaminant plumes are available.

A large number of field data compiled by Gelhar, Welty, and Rehfeldt (1992), presented in *A Critical Review of Data on Field-Scale Dispersion in Aquifers*, suggest that longitudinal dispersivity is a function of the travel distance and the aquifer type. For porous media and plume length scales on the order of a few hundred feet to a few thousand feet, the longitudinal dispersivity varies between 1% and 10% of the travel distance. Transverse and vertical dispersivity are often set to be 10% and 5% of the longitudinal dispersivity, respectively (Aziz et al., 2000; Domenico and Schwartz, 1997; ASTM, 1995). For this transport model, the longitudinal dispersivity was set to be 30 feet. After verification, the transverse and vertical dispersivity were set to be 10 percent and 0.1 percent of the longitudinal dispersivity, or 3.0 and 0.03 feet, respectively. The effective molecular diffusion coefficient was set to be 0.0008 ft^2/day, based on the literature values of molecular diffusion in water.

Retardation

Several geochemical reactions influencing the transport of contaminants result in the retardation of contaminant migration (dissolved contaminants moving slower than groundwater). The dominating reaction is adsorption of contaminants to the surface of soil particles. Adsorption can reduce the migration of dissolved contaminants moving through the groundwater by holding contaminant mass on the surface of soil particles. The retardation factor is the ratio of the groundwater seepage velocity to the rate that organic chemicals migrate in the groundwater. The degree of retardation depends on aquifer and constituent properties.

The retardation factor (R_e) is often estimated from soil properties and chemical data using the following variables: bulk density (ρ_b), effective porosity (n), organic carbon-water partition coefficient (K_{oc}), and fraction of organic carbon in uncontaminated soil (f_{oc}). The following expression was used to determine the retardation factor (Wiedemeier et al., 1999):

$$Re = 1 + \frac{K_d \rho_b}{n}$$

where:

K_d = is distribution coefficient and $K_d = f_{oc} \times K_{oc}$

Organic carbon-water partition coefficients were set to literature values of 126 liters per kilogram (L/kg) for TCE, 49 L/kg for cis-1,2-DCE, and 17 L/kg for 14D (PNL, 1989).

The ρ_b, n, and f_{oc} values in uncontaminated soil were determined based on Site-specific analytical data. Based on these values, the retardation factors were calculated by the MT3DMS model code using the retardation factor equation shown above.

Degradation

The model was developed based on the assumption that TCE, cis-1,2-DCE, and 14D are not undergoing significant biodegradation or chemical transformation. This assumption is conservative because it leads to higher estimated contaminant concentrations than the assumption that biodegradation or chemical transformations act to reduce contaminant mass.

Transport Verification

A fate-and-transport model is rarely calibrated using specific information about contaminant releases (e.g., masses of original releases, times of releases, etc.) because the factors are usually not known with adequate certainty. This information for the Site is not known. Consequently, transport model verification was conducted by simulating historical conditions and changes over time and comparing the simulated results to measured concentration data. Historical concentration data are included in the *Remedial Design Technical Memorandum for Field Sampling Results, and Monitoring Well Installation and Groundwater Sampling Results, Addendum Number 4* (URS, 2009). Transport model verifications were performed with TCE as the simulated contaminants. Although two treatability studies were completed in June 2006 that resulted in the reduction of TCE mass, this model validation approach was still considered an adequate method to use for verification.

Similar to flow calibration criteria, transport verification criteria, or the acceptable differences between model-predicted (computed) and observed concentrations (May 2009), were selected based on an empirical understanding of the potential errors in observed Site groundwater concentrations.

The simulation times for the verification runs were determined based on the availability of and the uncertainty associated with the historical groundwater concentration data. For the transport verification run, concentration data from 2004 were used as the initial concentration conditions. The verification simulation extended from 2004 through 2009. The transport for five years was simulated, and the simulated concentration plume shapes at the end of simulation period (2009) were compared to the sampled concentration data for 2009.

The observed concentrations in 2009 and the simulated concentration distributions in 2009 are provided on Figure 4. The simulated concentration distributions at the end of the simulation (2009) were compared with the concentrations observed in May 2009. The qualitative comparison indicates that, in general, the simulated concentration distributions matched the interpolated concentration distributions of sampled concentration data from 2009, verifying that contaminant transport could be simulated adequately.

IV. CAPTURE ZONE ANALYSIS AND PARTICLE TRACKING

After the steady-state flow model calibration was successfully completed, particle tracking was performed. Particles generated using MODPATH may be calculated to travel either forward (downgradient) through the model simulation or backward (upgradient from a specific point, such as an extraction well). Forward traveling particles provide information about the predicted route of groundwater over the model run. The particle starting locations are selected to predict groundwater migration from specific locations through time. Forward traveling particles that are captured in an extraction well might not, however, predict the full capture zone for that well. They only predict the travel route from the starting location of the particle. Backward traveling particles predict where groundwater has traveled to reach a specific location. Particles traveling backward from an extraction well would predict the extent of that well's capture zone. Use of forward and backward traveling particles, therefore, depends on the particular questions being asked in the modeling effort. Particles on the figures are shown as black squares initially (year 0) and then as arrows (year 0 + n years); lines and arrows indicate particle flow paths, and the distance between arrows represents a period of five years.

For this model, particles were set to begin upgradient of the Site and were expected to travel through the area of groundwater impacted by the Site COCs (TCE, cis-1,2-DCE, and 1,4-D).

Predictive Scenarios were conducted to evaluate groundwater capture within the Cooper Drum Site model. Figure 5 illustrates the predicted flow regime or initial conditions without the influence of extraction and/or injection wells (current condition). Figures 6 through 8 show the results of predictive scenarios for the model using recently installed Extraction Well Number 3 (EW-3) pumping at 15, 20, and 30 gallons per minute (gpm). The purpose of the pumping scenarios was to see how different pumping rates would influence the particle flow paths. Starting locations for the forward traveling particles were set along the perimeters of the target area. Backward traveling particles are not used for this analysis because the forward traveling particles (and their starting locations) are most relevant for evaluating target area capture. Particles on the figures are shown as black squares initially (year 0) and then as arrows (year 0 + n years); lines and arrows indicate particle flow paths, and the distance between arrows represents a period of five years.

Figure 6 illustrates that predictive capture would occur within the Site using one extraction well with a pumping rate of 15 gpm. Predicted travel times for particles beginning at the north end of the target zone to the extraction well ranges from approximately 15 to 20 years. All of the particle flow paths to the southwest, southeast, and northeast, beginning outside of the target zone, remain outside of the area of predicted capture.

Figure 7 illustrates that predictive capture would occur within the Site using one extraction well with a pumping rate of 20 gpm. Predicted travel times for particles beginning at the north end of the target zone to the extraction well are approximately 15 years. Some of the particle flow paths to the southwest and northeast, beginning outside of the target zone, remain outside of the area of predicted capture.

Figure 8 illustrates that predictive capture would occur within the Site using one extraction well with a pumping rate of 30 gpm. Predicted travel times for particles beginning at the north end of the target zone to the extraction well are approximately 15 years. Particle flow paths to the northeast, beginning outside of the target zone, remain outside of the area of predicted capture; however, particle flow paths to the southwest and southeast are predicted to be captured. This capture zone encompasses an area larger than the Site and could influence off-site plume migration, specifically in the southeast area.

V. FATE-AND-TRANSPORT SIMULATIONS

The model predictions were carried out based on the calibrated 3-D transport model. Eleven fate-and-transport scenarios were chosen to be simulated. A brief description of each of those scenarios is presented in Table 3.

The total model simulation time was 50 years from 2009. All estimated times to cleanup summarized in Table 3 at 50 years should be considered the minimum time to reach cleanup standards. The model was used to predict the times required for the COC plumes to reach the applicable cleanup standards of 5 μg/L for TCE, 6 μg/L for cis-1,2-DCE, and 6.1 μg/L for 14D.

Table 3. Fate-and-Transport Model Simulations, Cooper Drum Site

Scenario	Description	Purpose
1	EW-3 pumping at 30 gpm	Assess time to cleanup source area using one well.
2	EW-3 (30 gpm), SEW-1 (25 gpm)	Assess time to cleanup source area using two wells.
3	EW-3 (30 gpm), SEW-1 (15 gpm)	Assess impact of reducing SEW-1 from 25 to 15 gpm.
4	EW-3 (30 gpm), EW-2 (8 gpm) and EW-4 (4 gpm). EW-2 and EW-4 screened across Shallow and Intermediate Gaspur Aquifer only.	Assess impact in source area by adding two additional wells.
5	EW-3 (30 gpm), SEW-1 (10 gpm), EW-2 (8 gpm), and EW-4 (4 gpm)	Assess impact on cleanup time by adding four wells to pumping array.
6	Same as Scenario 4, but all wells screened across entire Gaspur Aquifer.	Assess impact to cleanup time by increasing screen length.
7	Same as Scenario 5, but all wells screened across entire Gaspur Aquifer.	Assess impact to cleanup time by increasing screen length.

Table 3. (Continued)

Scenario	Description	Purpose
8	Same as Scenario 2, but added two injection (IW-1 and IW-2) wells (12.5 gpm per well) in source area.	Assess impact to cleanup time by adding two additional injection wells.
9	Same as Scenario 2, but reduced mass within treatment zone to 50 µg/L.	Assess impact of implementing ISCO mass removal (removing mass to 50 µg/L).
10	Same as Scenario 9, but reduced mass within treatment zone to applicable MCL.	Assess impact of implementing ISCO mass removal (removing mass to applicable MCL).
11	Added 350-foot bio-barrier across entire Gaspur Aquifer (down to Lower Gaspur) along Southern Avenue. Source reduced to 50 µg/L and EW3 pumping at 30 gpm.	Assess impact to cleanup times for entire plume by implementing a bio-barrier.

gpm = gallons per minute
ISCO = in situ chemical oxidation
MCL = maximum contaminant limit
µg/L = micrograms per liter

For these simulations, it was assumed that there was no further contaminant input into the groundwater flow system as of 2009, i.e., all modeled source boundary conditions were turned off in the model. While this is unlikely based on field observations, no information is available to improve this assumption. However, it is noted that concentrations at the suspected source areas around certain wells have been dropping, suggesting that contaminant input is gradually decreasing.

Figure 9 shows the model predictions for the time required to reach the cleanup standard for each chemical within the shallow, intermediate and lower Gaspur aquifer. It is important to note that for these predictions, it was assumed that all sources are inactive and each estimated time to cleanup should be considered as a best-case scenario and non-conservative. Table 4 summarizes the results of each of the fate and transport model scenarios. Figure 10 shows the location of downgradient extraction well (EW-3), source area extraction wells (EW-2, EW-4 and SEW-1), source area injection wells (IW-1 and IW-2) and the proposed bio-barrier (Scenario 11).

Table 4. Results of Fate-and-Transport Model Simulations, Cooper Drum Site

Scenario	Cleanup Times in Year TCE -Shallow/Intermediate/Lower Gaspur Aquifer cis-1,2-DCE - Shallow/Intermediate/Lower Gaspur Aquifer 14D- Shallow/Intermediate/Lower Gaspur Aquifer
1	TCE - 43/50/50 cis-1,2-DCE - 45/50/50 14D - 14/50/43
2	TCE - 12/50/47 cis-1,2-DCE - 23/50/47 14D - 5/36/18

Table 4. (Continued)

Scenario	Cleanup Times in Year TCE -Shallow/Intermediate/Lower Gaspur Aquifer cis-1,2-DCE - Shallow/Intermediate/Lower Gaspur Aquifer 14D- Shallow/Intermediate/Lower Gaspur Aquifer
3	TCE - 25/50/50 cis-1,2-DCE - 23/50/50 1,4-D - 7/47/24
4	TCE - 10/44/47 cis-1,2-DCE - 15/50/39 1,4-D - 5/37/18
5	TCE - 8/36/43 cis-1,2-DCE - 10/43/34 1,4-D - 4/22/17
6	TCE - 12/44/49 cis-1,2-DCE - 12/50/39 1,4-D - 11/27/21
7	TCE - 9/36/43 cis-1,2-DCE - 10/43/34 1,4-D - 4/22/17
8	TCE - 5/25/40 cis-1,2-DCE - 9/28/30 1,4-D - 3/13/15
9	TCE - 10/50/48 cis-1,2-DCE - 6/43/30 1,4-D - 5/32/23
10	TCE - 6/27/25 cis-1,2-DCE - 5/32/23 1,4-D - 4/21/10
11	TCE - 36/35/36 cis-1,2-DCE - 24/27/25 1,4-D - 15/17/12

cis-1,2-DCE = cis-1,2-dichloroethene
TCE = trichloroethene
1,4-D = 1,4-dioxane

VI. SUMMARY

The six-layer transient groundwater flow and transport models, developed using available Site-specific data, were calibrated to mimic 2009 groundwater elevations to within 10 percent.

Particle tracking, based on the flow model, was used to help predict the migration path of groundwater particles associated with contaminant plumes at the Site. Based on particle tracking capture zone analysis, EW-3 could be operated at less than 30 gpm and still provide adequate plume capture.

Eleven fate-and-transport scenarios were simulated to evaluate the impacts different remediation technologies would have on overall cleanup times. All transport model simulations assume no source mass is present at the site and that decay is not occurring at the site. The conclusions are as follows:

- Addition of source area extraction (SEW-1, EW-2 or EW-4) reduces cleanup times (Scenarios 2 through 10).
- Scenario 8 (two injection wells (IW-1 and IW-2) added near source area) appears to have a beneficial use in reducing cleanup times to 40 years.
- Scenario 10 reduced cleanup time to 25 years, but this assumed that all mass in the source area is reduced to the applicable maximum contaminant limit (MCL) by in situ chemical oxidation (ISCO), prior to groundwater extraction.
- Scenario 11 (bio-barrier) may reduce cleanup time by approximately 3-6 years.

VII. MODEL USE, LIMITATIONS, AND UNCERTAINTY

Data for edge boundary conditions interpolated over distance are sparse, leading to unquantifiable errors along the edges of the model. This error could be mitigated with additional groundwater elevation data farther from the site. With those data, the model domain could be enlarged so that residual errors around the edges of the model would have even less relevance to the areas of interest.

Particle-tracking calibration cannot account for retardation of chlorinated solvents, so the simulated groundwater velocities may be greater than actual plume migration velocities.

This groundwater flow model is a useful predictive tool that incorporates nearly all available data within the model domain. Numerical models can be powerful tools, if used appropriately, to assist in making management decisions for the former Cooper Drum groundwater cleanup program. This model can be used to help quantify the effectiveness of current cleanup efforts at the Site. Use of this model is subject to limitations; like any computer model, it has inherent uncertainty.

Groundwater models are simplifications of the natural environment and, therefore, have recognized limitations. Hence, some uncertainty exists in the ability of this model to predict groundwater flow. Effort was expended to minimize model uncertainty by using real world values as model input whenever available. Uncertainty of the model output reflects uncertainties in the conceptual model, the input parameters, and the ability of the mathematical model to simulate real world conditions adequately.

VIII. DISCLAIMER

The limited objective of this effort, the ongoing nature of the project, and the evolving knowledge of Site conditions and chemical effects on the environment and human health all must be considered when evaluating this memorandum because facts may become known that may make this document premature or inaccurate.

This memorandum was prepared by URS under the review of registered professionals. The conclusions and recommendations in this memorandum are based on URS' evaluation of the data. The interpretation of the data and the conclusions drawn were governed by URS' experience and professional judgment.

VIII. REFERENCES

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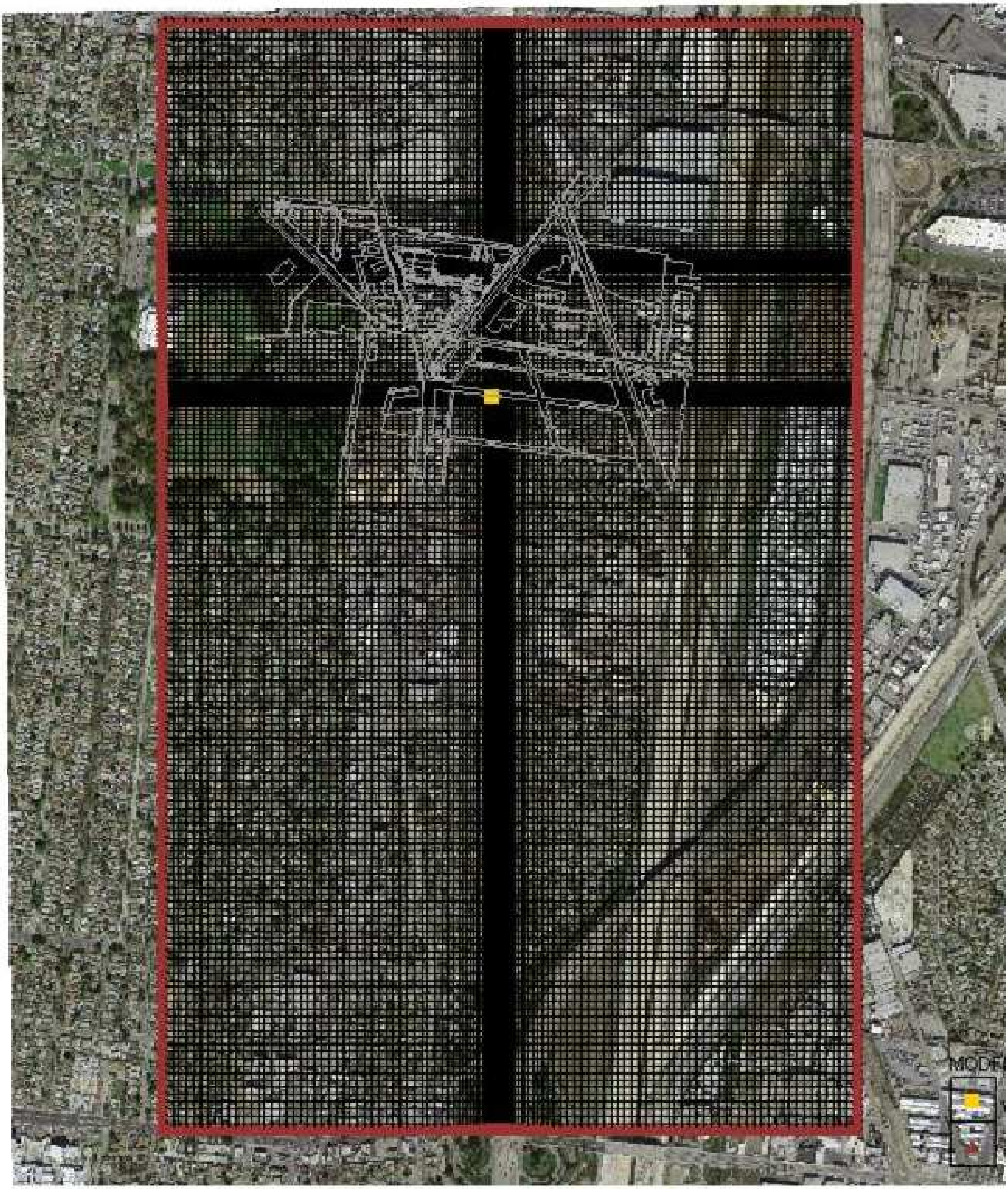
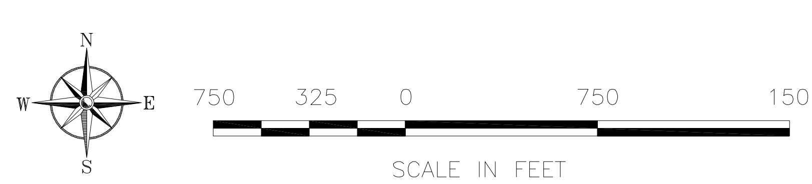
Attachments

Figure 1 – Cooper Drum Site and MODFLOW Grid
Figure 2 - Hydraulic Conductivity Distribution, Layers 3, 4, and 5
Figure 3 – Simulated Versus Observed Heads (All Layers)
Figure 4 – Fate-and-Transport Verification (Simulated Versus Observed)
Figure 5 – Particle Tracking (No Pumping)
Figure 6 – Particle Tracking (15 gpm)
Figure 7 – Particle Tracking (20 gpm)
Figure 8 – Particle Tracking (30 gpm)
Figure 9 – Fate-and-Transport Cleanup Scenarios
Figure 10 –Location of Extraction Wells and Proposed Bio-Barrier

Appendix A – Results of May 2009 Aquifer Test

FIGURES





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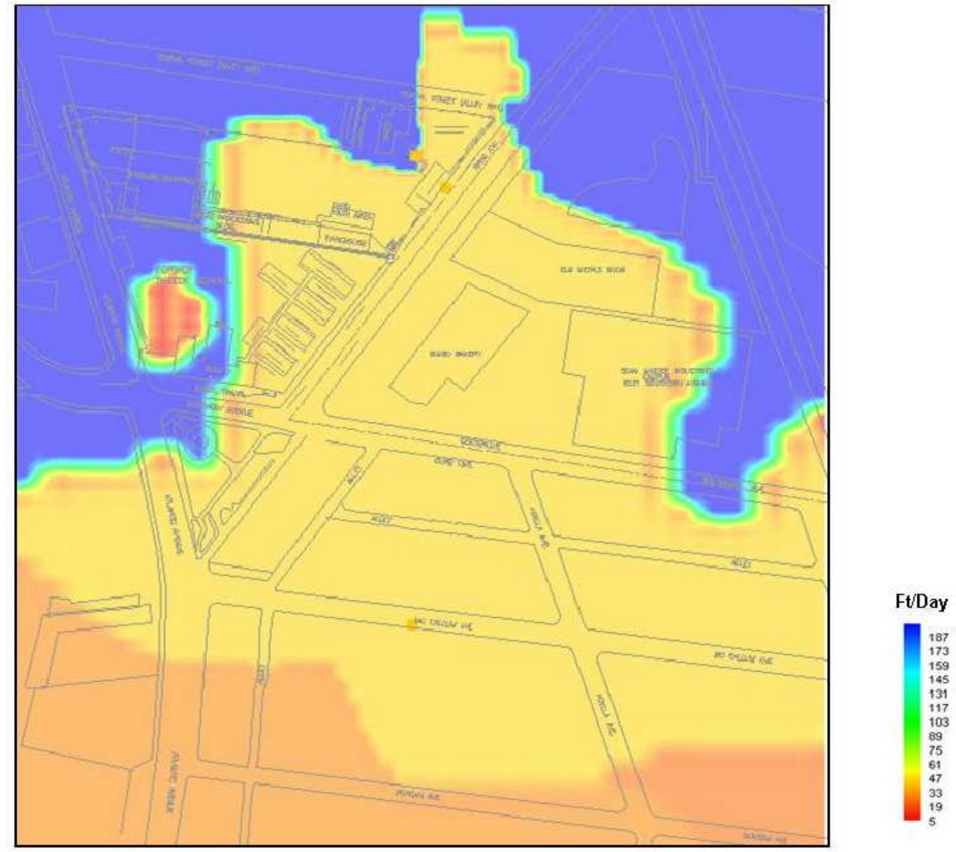
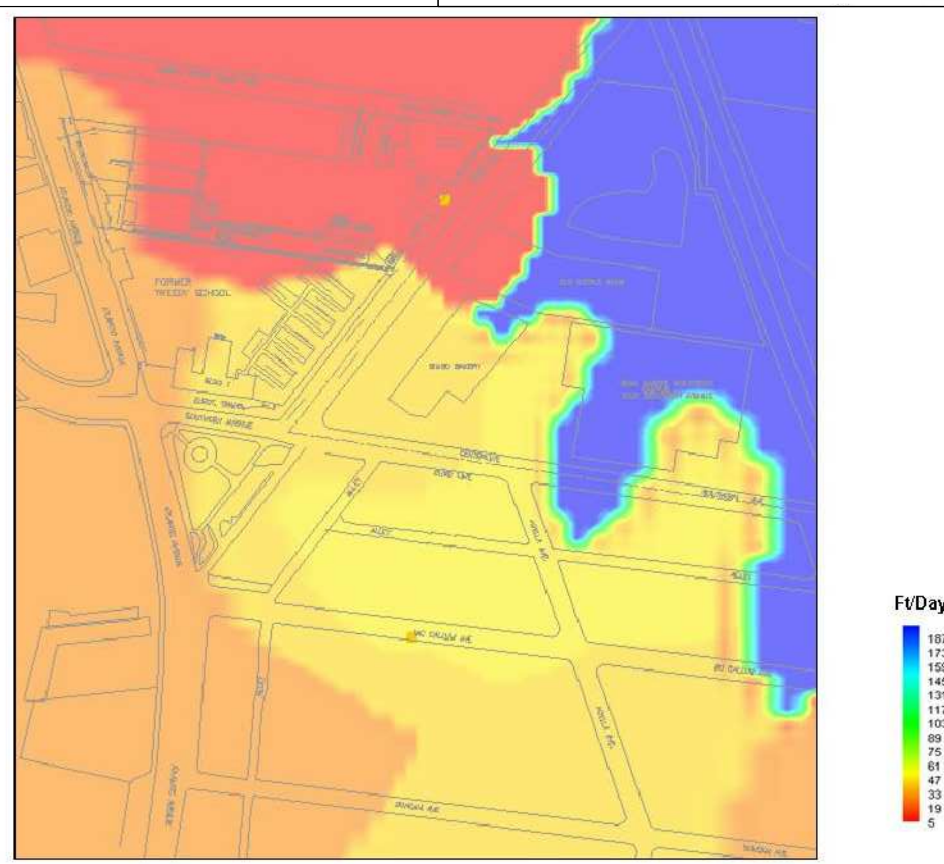
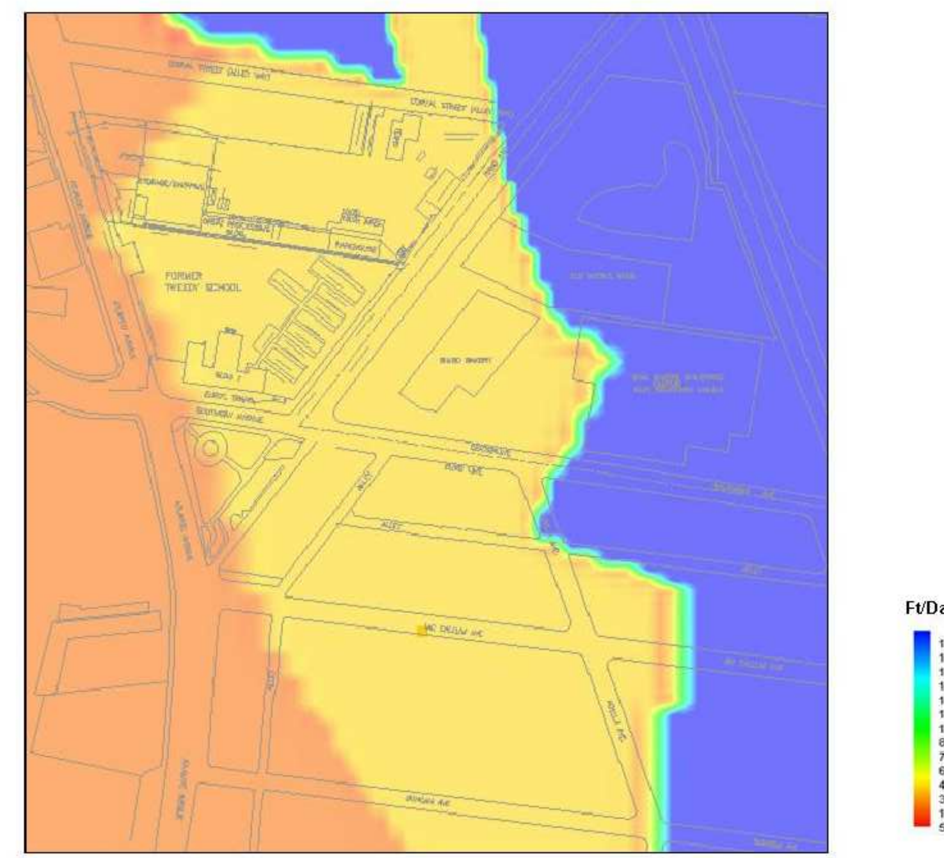
Cooper Drum Superfund Site South Gate, CA	Figure 1 COOPER DRUM PROJECT SITE AND MODFLOW GRID



Cooper Drum Hydraulic Conductivity (Shallow Gaspur)



Cooper Drum Hydraulic Conductivity (Intermediate Gaspur)



Cooper Drum Hydraulic Conductivity (Lower Gaspur)

PLOT BY: ROBERT_P_TAYLOR - Jan 04, 2010 - 1:35:19pm

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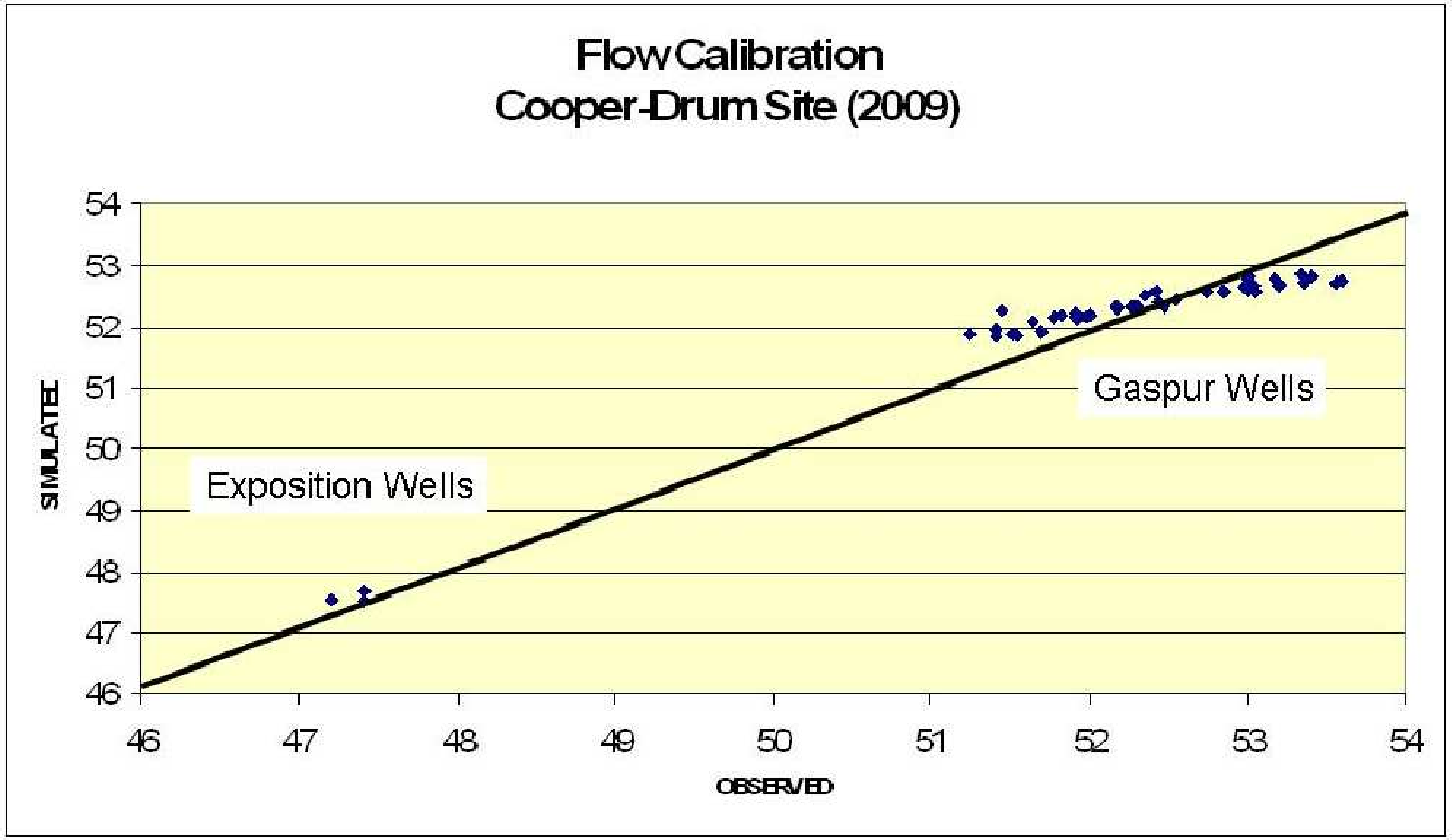
FIGURE 2
HYDRAULIC CONDUCTIVITY DISTRIBUTION
SHALLOW, INTERMEDIATE, LOWER GASPUR



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Cooper Drum Company South Gate, California	FIGURE 3 FLOW CALIBRATION ALL LAYERS

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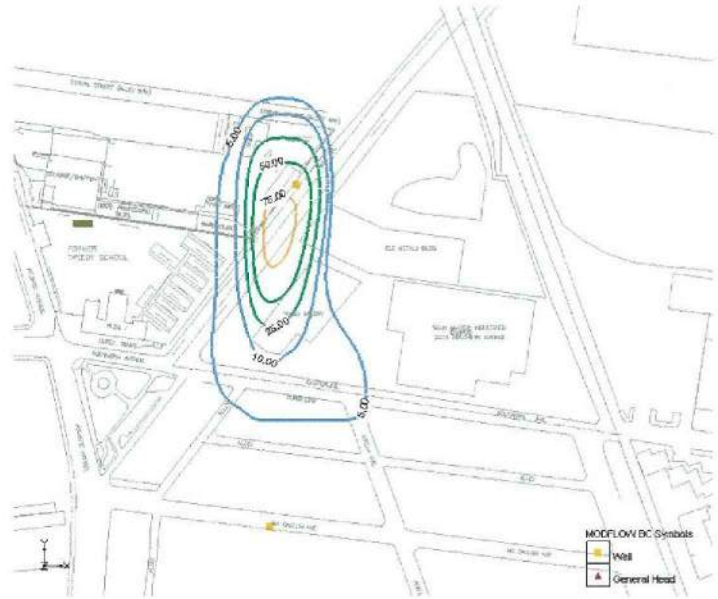
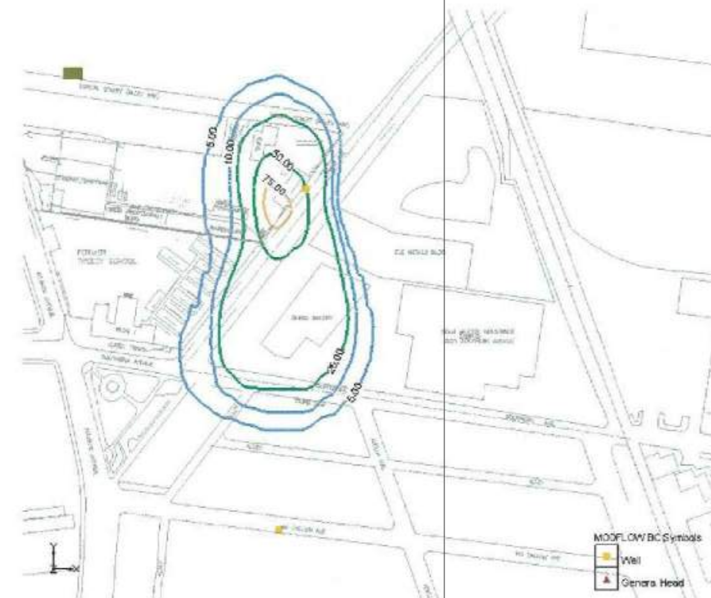
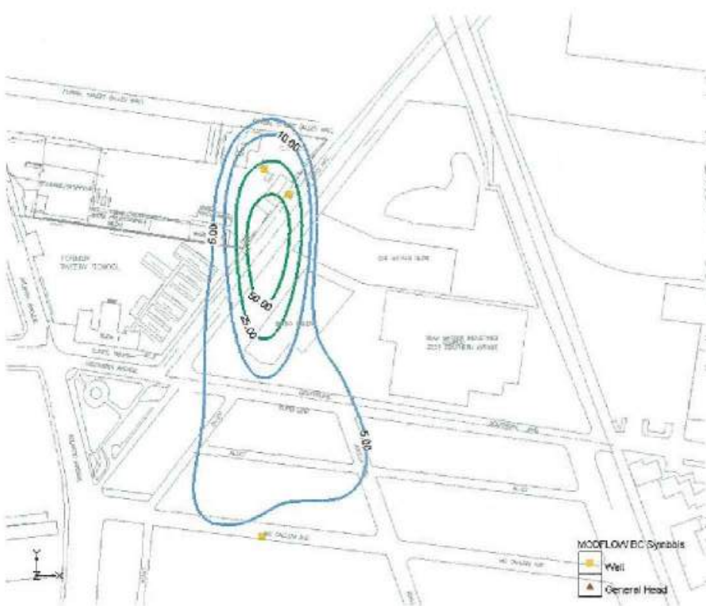


TCE 2004-2009 Simulated

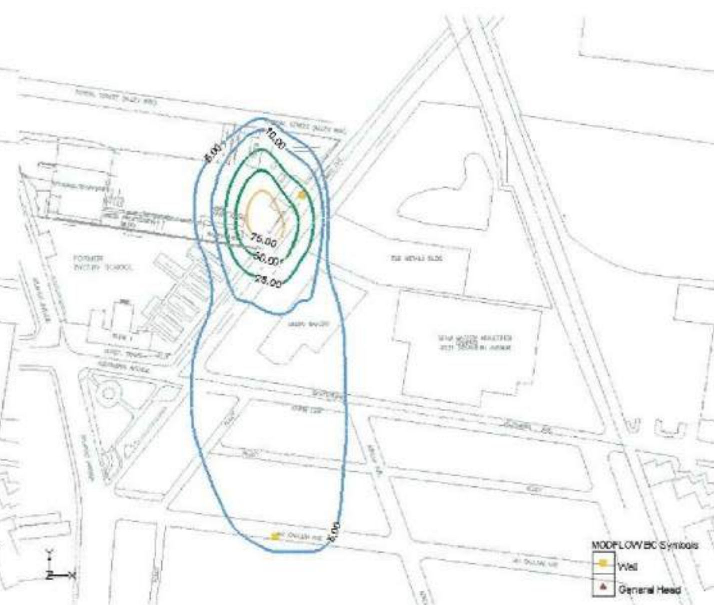


TCE 2009 Observed

(CONTOURED INTERVAL 5, 10, 25, AND 75 ug/L)



DCE 2004-2009 Simulated



DCE 2009 Observed

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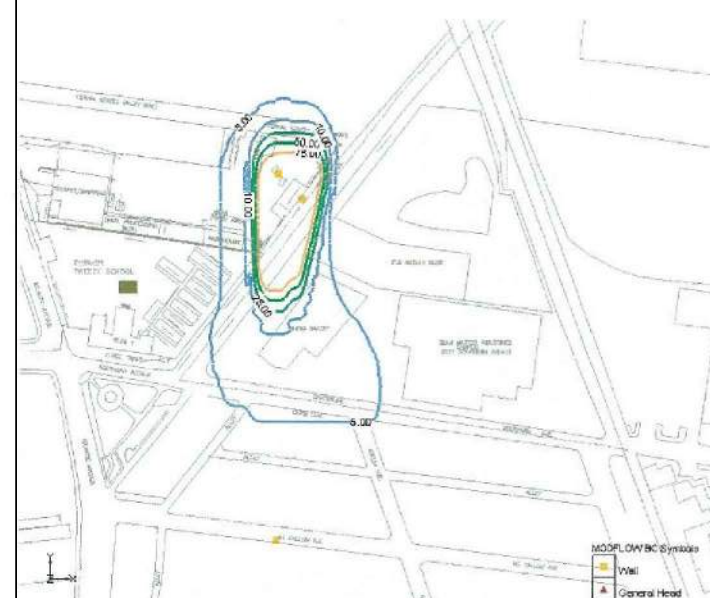
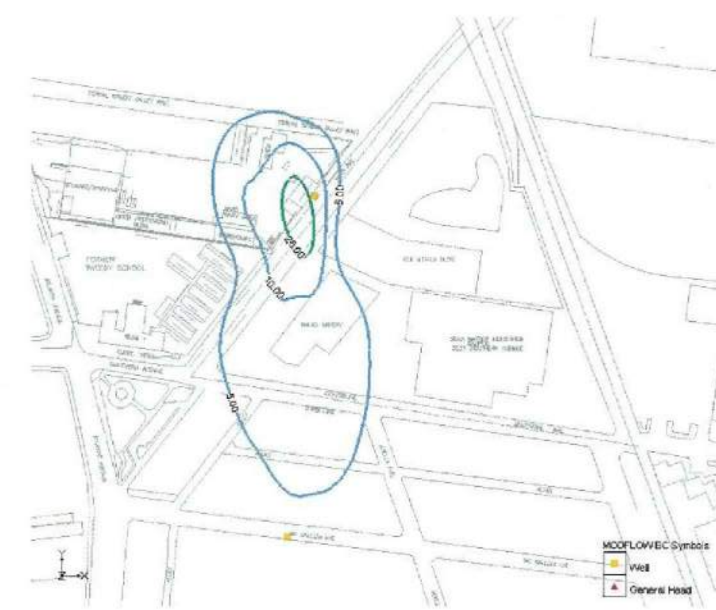


1-4 Dioxane 2004-2009 Simulated



1-4 Dioxane 2009 Observed

(CONTOURED INTERVAL 5, 10, 25, AND 75 ug/L)

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FIGURE 4
TRANSPORT VERIFICATION
TCE, DCE, DIOX

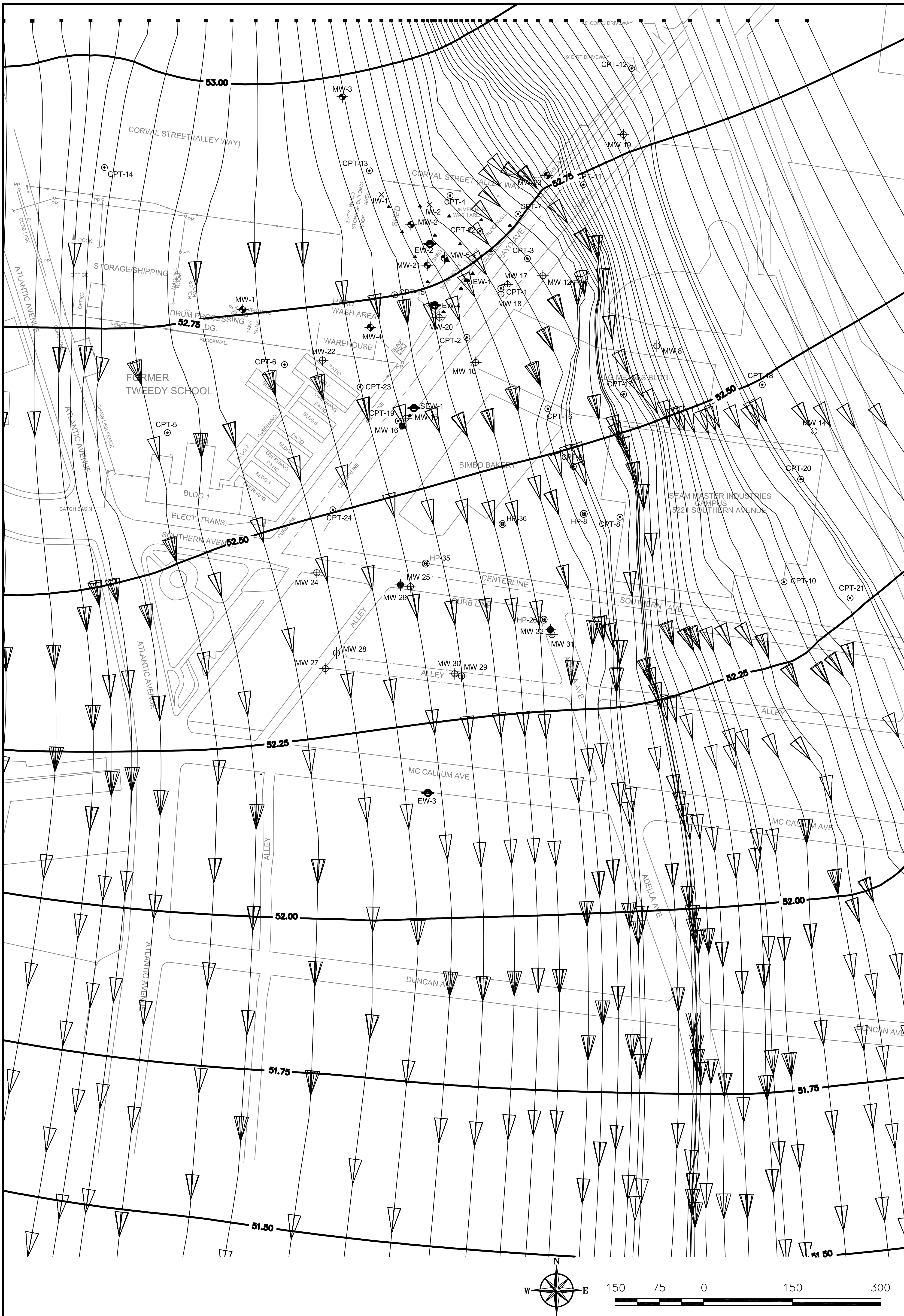

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Figure 5
PARTICLE TRACKING
(NO PUMPING)

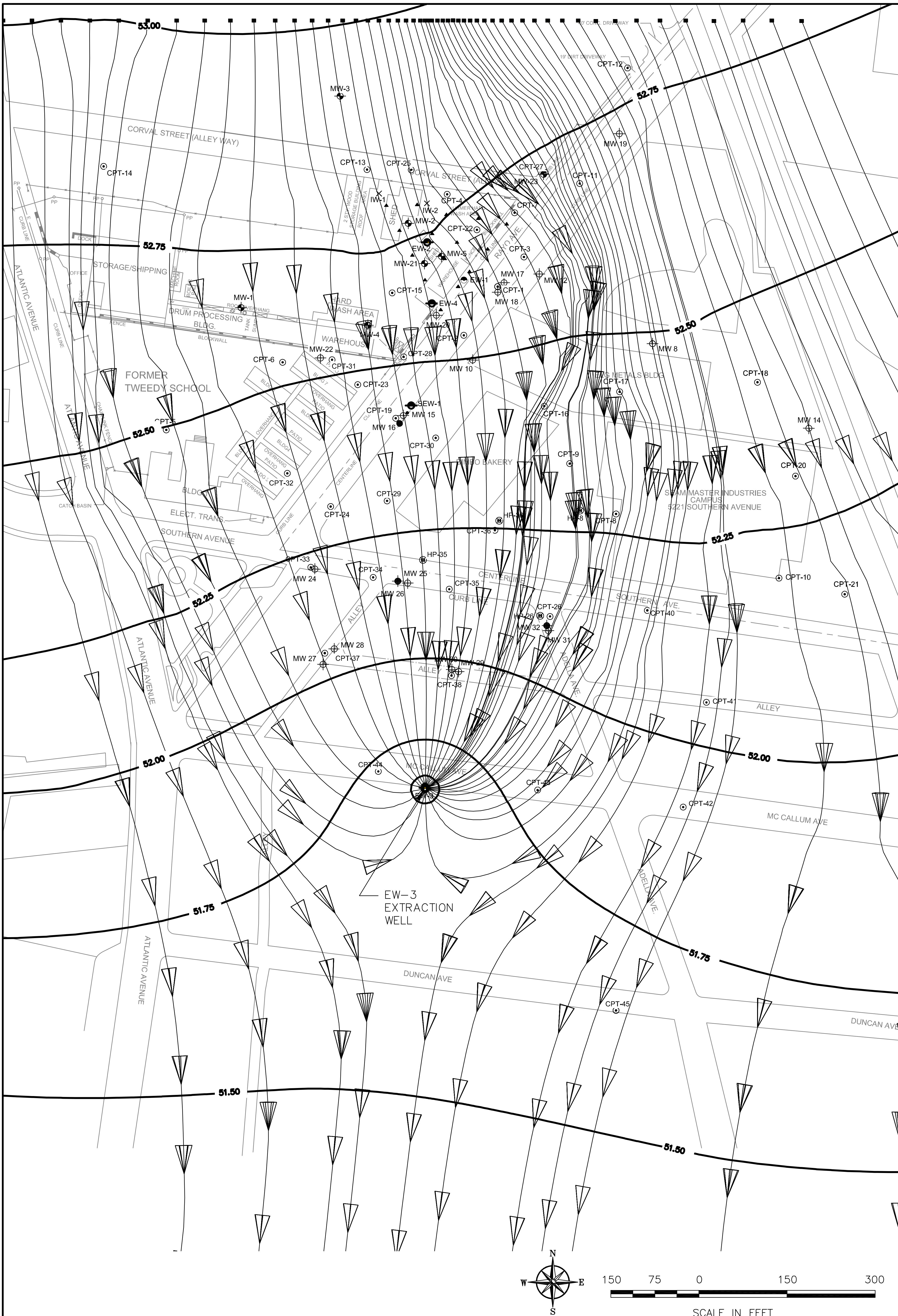

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Figure 6
PARTICLE TRACKING
(15 gpm)

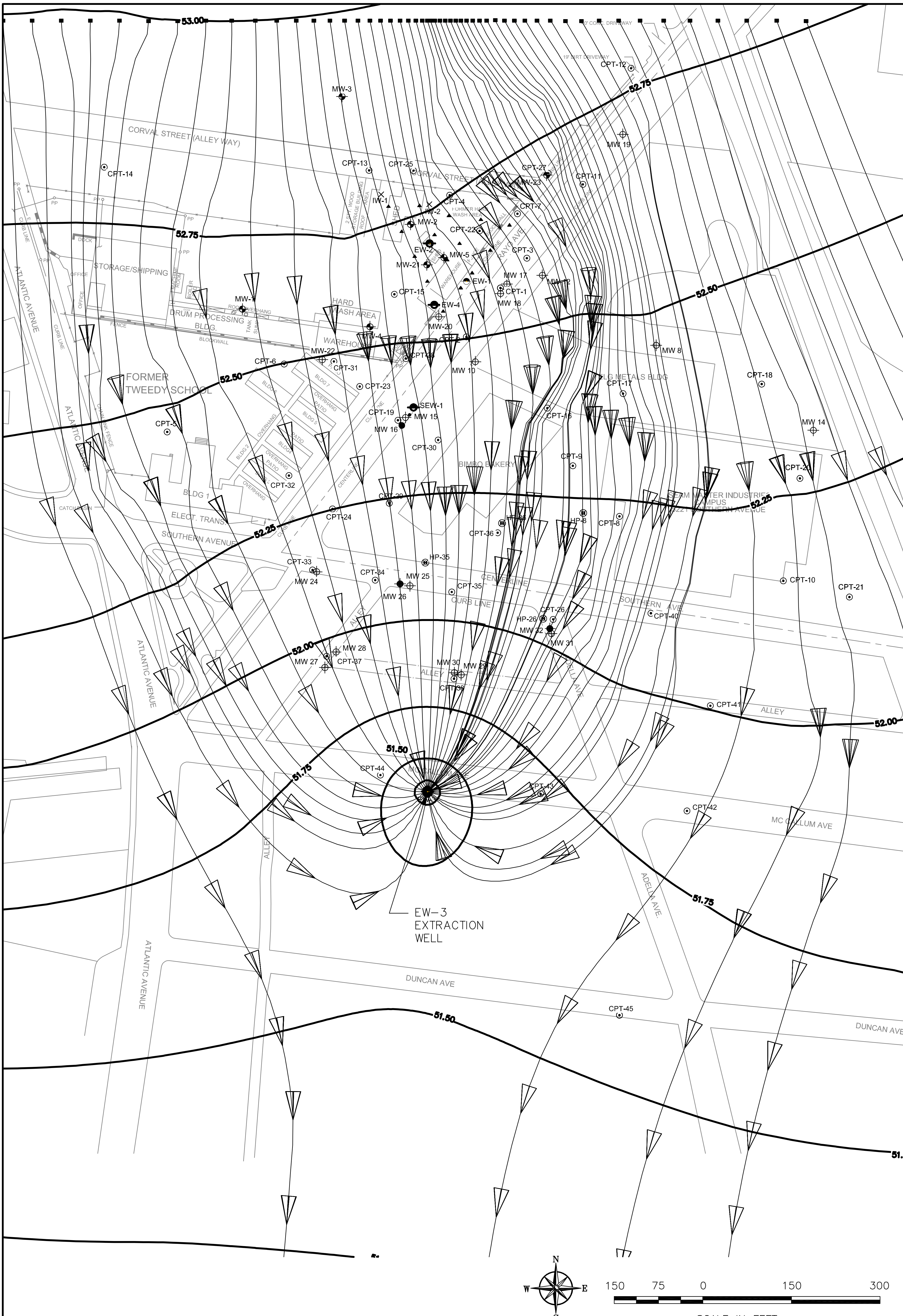

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Figure 7
PARTICLE TRACKING
(20 GPM)

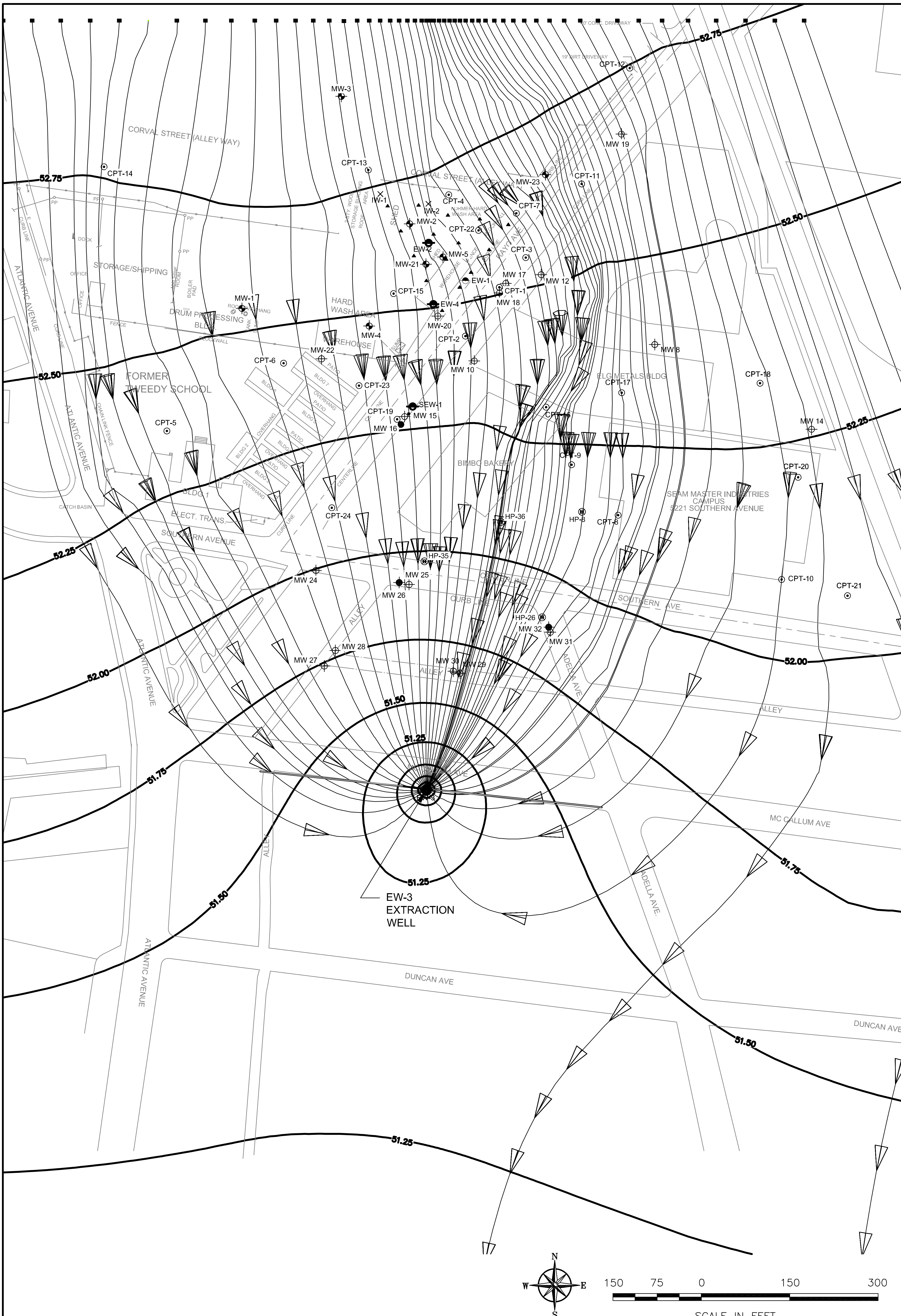

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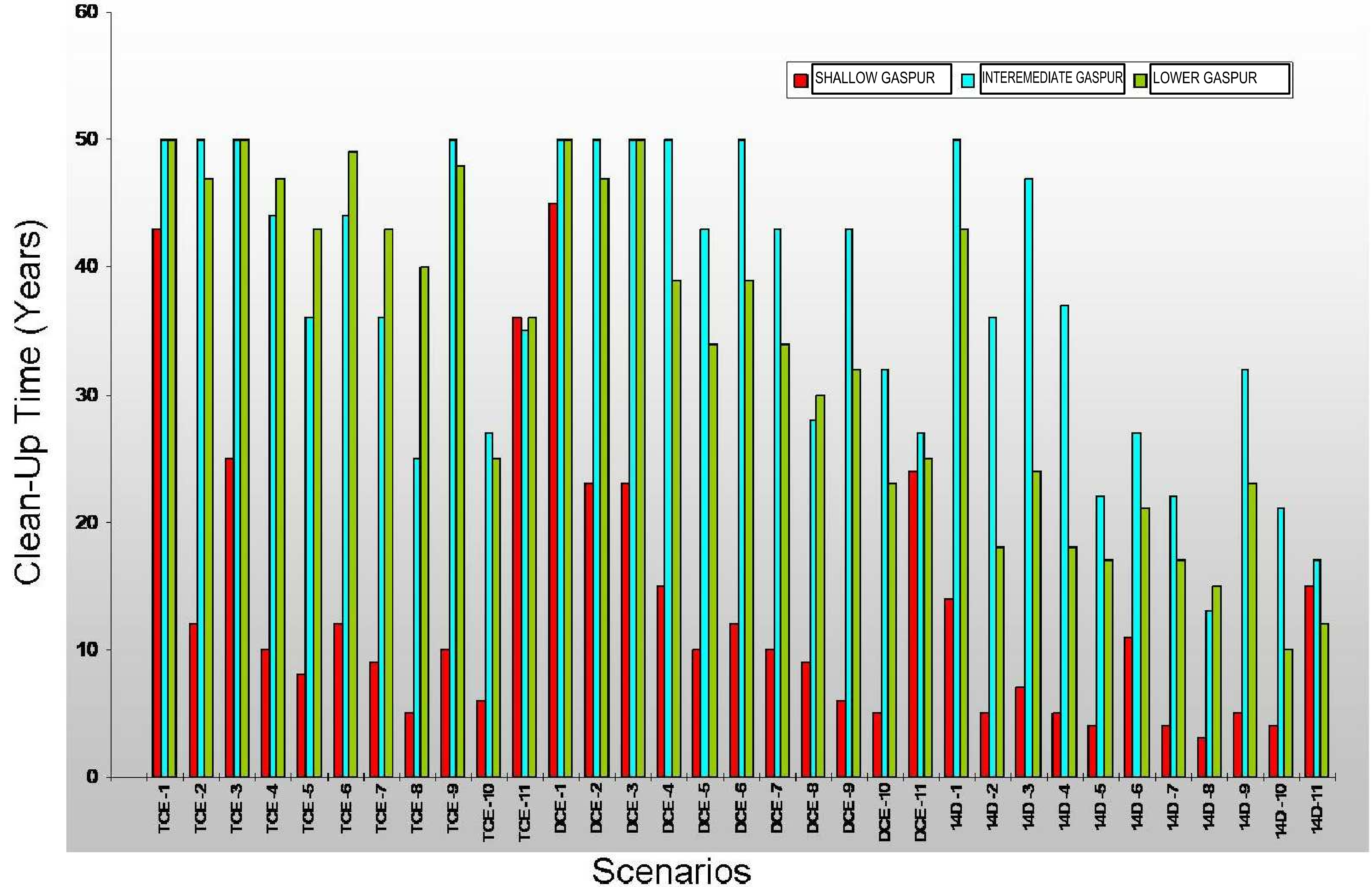
Figure 8
PARTICLE TRACKING
(30 GPM)



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Cooper Drum Company South Gate, California	FIGURE 9 FATE AND TRANSPORT CLEAN-UP SCENARIOS

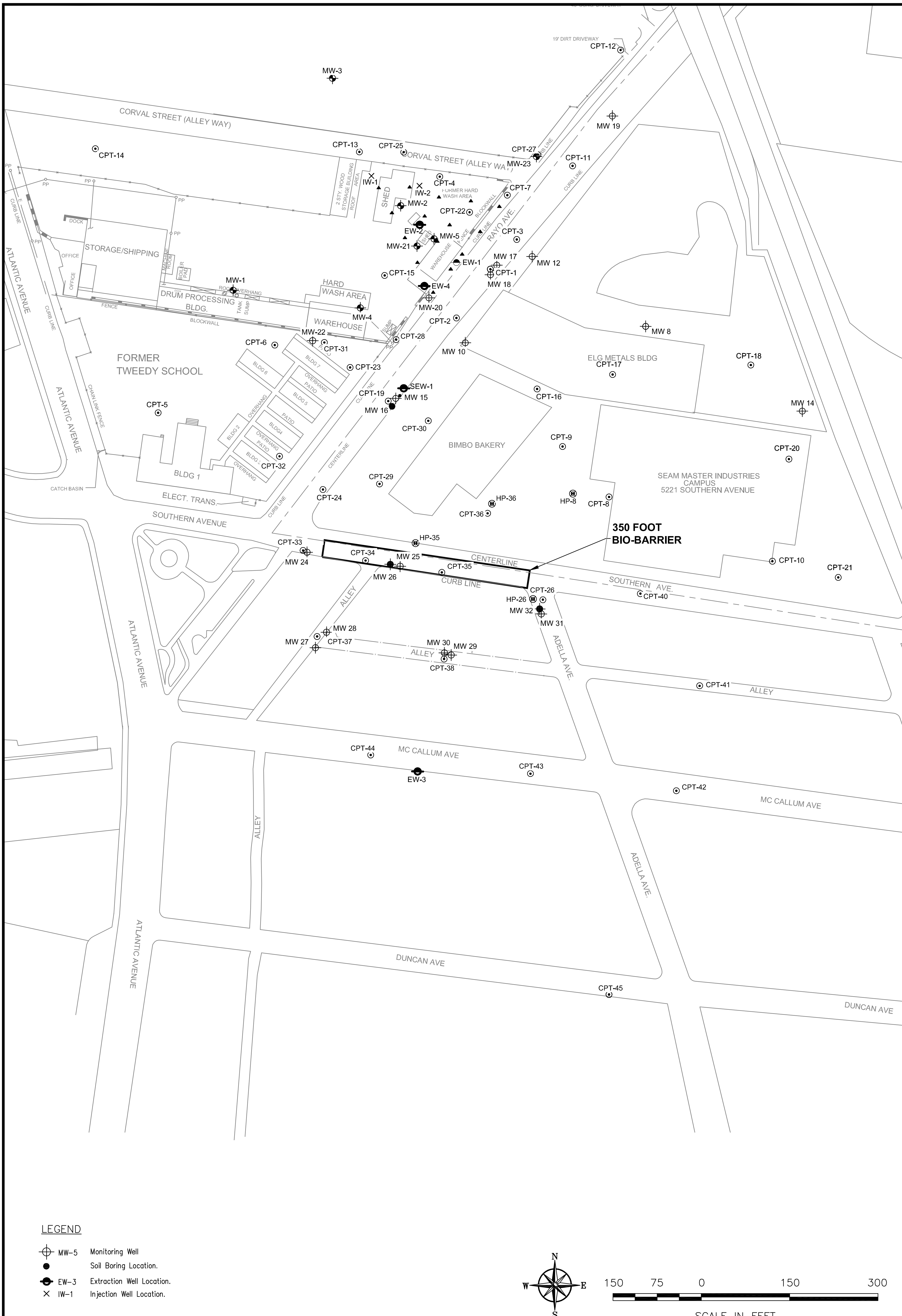

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Figure 10
APPROXIMATE LOCATION OF PROPOSED
BIO-BARRIER LOCATION